GROEP T
LEUVEN ENGINEERING COLLEGE

“SolarBullet”

Report of SSV: Part 2

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Contents

Collision test measurement and calculated data:

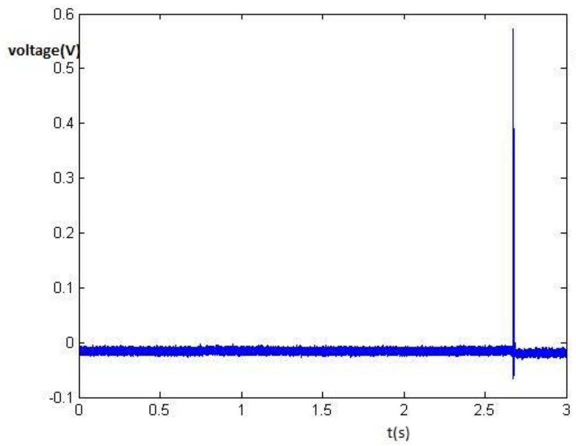
In this collision test, we hit our SSV with a pendulum(with mass = 0.735kg) raised to certain height. We measured the voltage from PCB 200C20 load cell at the time of collision. Later the measured voltage is converted to Force(N) according to the sensitivity of the load cell.

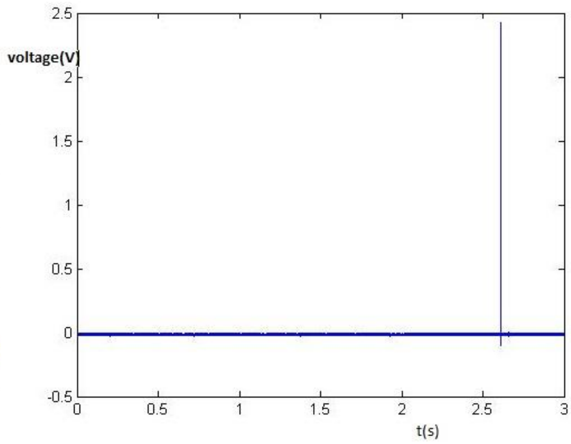
Sensitivity of the load cell = $56.2\frac{\mathrm{mV}}{\mathrm{kN}}$

test	Voltage*100 (V)	Force (N)	Height (cm)	Potential Energy(J)	Velocity (m/s)	Velocity Car(m/s)	delta h (m)
1	0.57188	101.75801	15.2	0.0288414	0.280142821	0.343174955	0.004
2	2.426787	431.81263	19.3	0.32446575	0.939627586	1.151043793	0.045
3	3.603713	641.23007	21.5	0.48309345	1.146533907	1.404504036	0.067
4	3.978412	707.90249	24.2	0.6777729	1.358042709	1.663602319	0.094
5	4.256583	757.39911	26.1	0.81476955	1.488979516	1.823999907	0.113
6	7.543107	1342.1899	31.6773476	2.284047636	1.819707561	2.229141762	0.168773476

The peak voltage in the graph below show the voltage recorded when the pendulum hit the SSV.This peak voltage is then converted to the force during collision using sensitivity of the load cell as discussed.

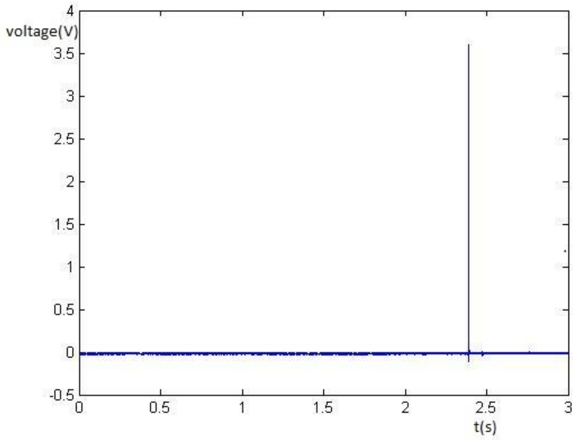
The other points in the graph might be the result of noise from the surroundings.



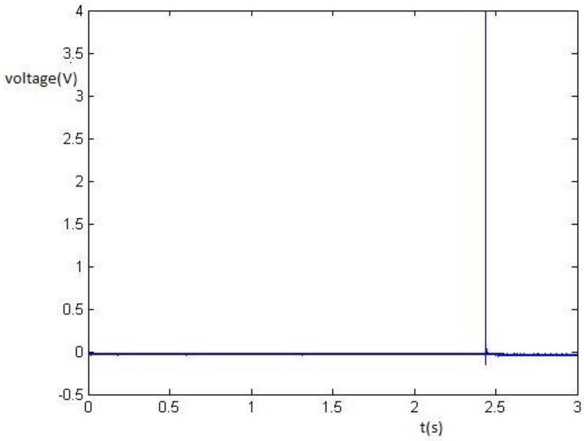


Test 1

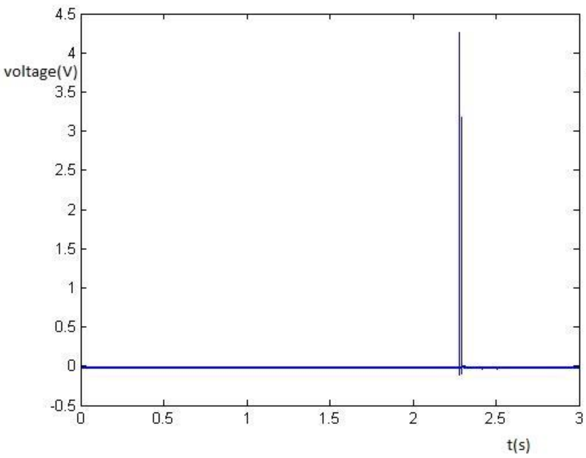
Test 2



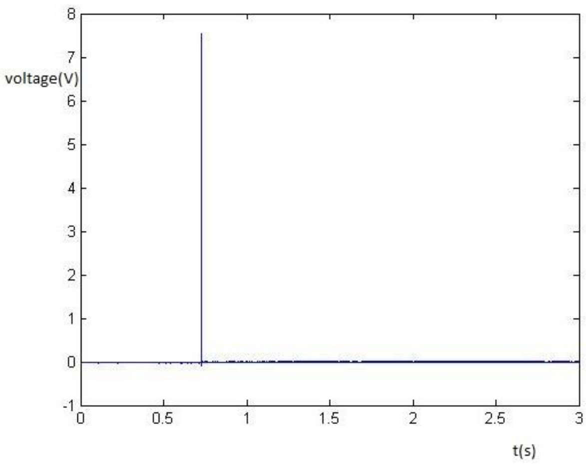
Test 3



Test 4



Test 5



Test 6

<u>Calculation example of test 1:</u>

Voltage = 0.57188 V,

We use the sensitivity of the load cell.

Force = $\frac{0.57188 \text{ V}*10^4}{56.2 \frac{\text{mV}}{\text{kN}}}$ = 101.75801 N

Potential Energy: m*g*h = (0.735kg)*(9.81$\frac{m}{s^2}$)*(0.004m)

= 0.0288414J

Velocity of the pendulum at the moment of collision:

$V_{pendulum}$ $= \sqrt{2 * g * h}$

$= \sqrt{2 * (9.81\frac{m}{s^2}) * (0.004m)}$

$=0.280142821\frac{m}{s}$

Initial Velocity of the car after the collision :

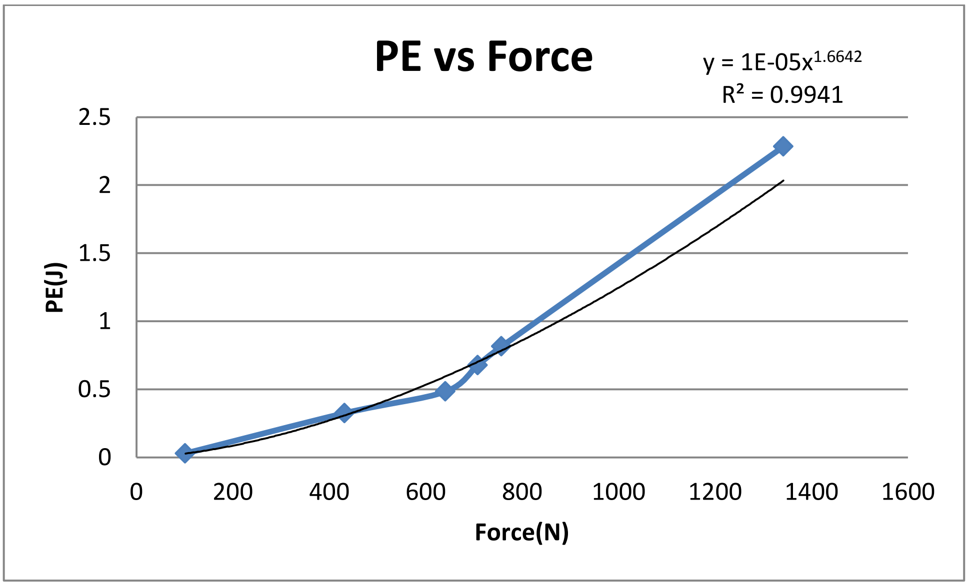
$V_{ssv} = \frac{m_{pendulum}}{M_{SSV}} * V_{pendulum}$

$= \frac{0.735kg}{0.600kg} * (0.280142821\frac{m}{s})$

$= 0.343174955\frac{m}{s}$

The last test (6th) was performed with SSV running towards the stationary pendulum. In this case, we only had one known value in the beginning, which was the voltage measured during the collision. By extrapolating the curve (Force vs Potential energy) obtained with the previous five test, we calculated all other values.

The experiment allows us to predict the velocity of the SSV required to achieve certain height of the ball in the real race, as the pendulum has same mass as the ball. However there are limitations and error factors in the experiment that can limit the accuracy of our calculations. We assume that the collision was elastic, plus our mass of car was a lot less than the optimal mass calculated theoretically. Also in the race, there will be friction between the ball and the ramp, which is excluded in our experiment.



This collision test point out weaknesses of our SSV. The hitter part of the car was too narrow, so it could miss the ball or hit it on the side. It was also too long and narrow so there was a chance it would break down. This indicated that we have to make the hitter broader and stronger.

Fig: old design

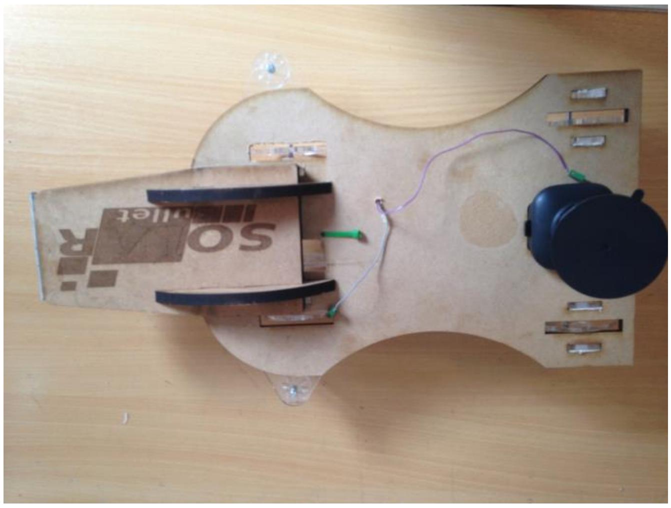
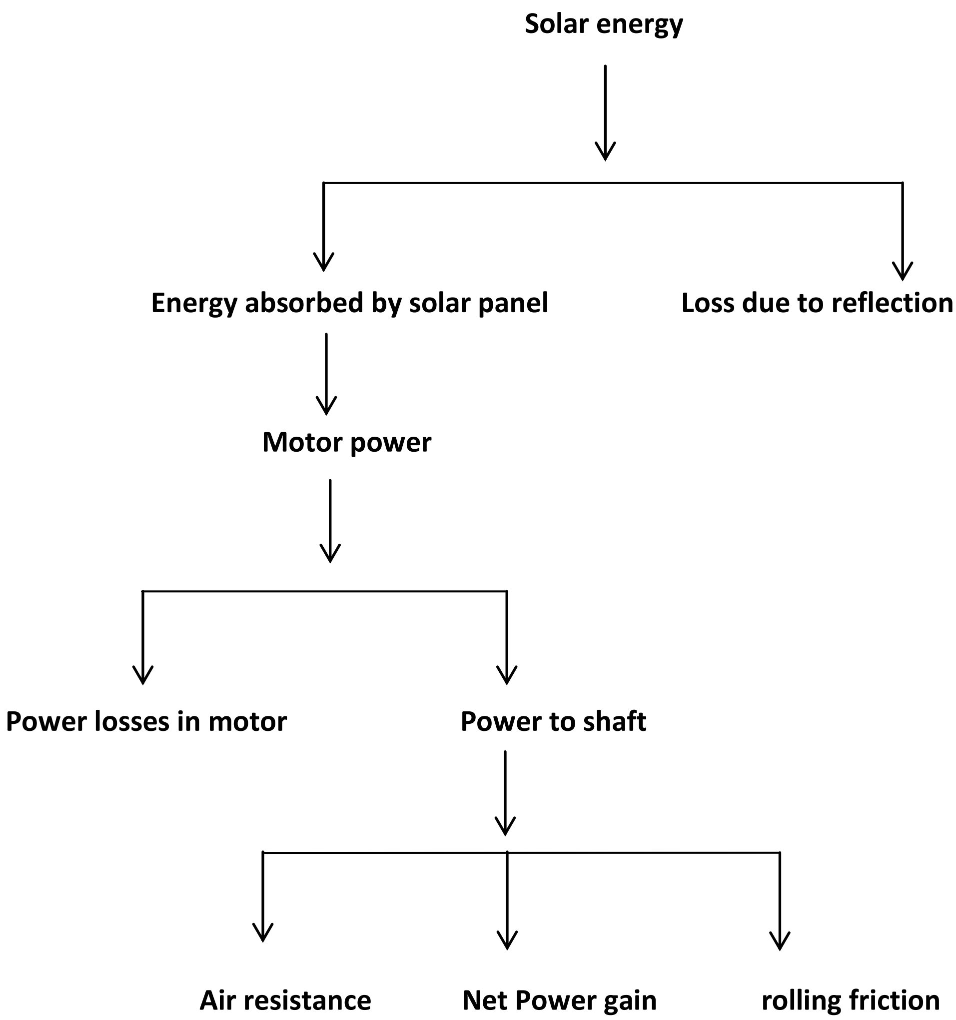


Fig:new design

Power flow through your SSV with the aid of Sankey diagrams.

Sankey Diagram



Solar energy absorbed by panel:

Solar energy per square meter = 800 W/mts^2

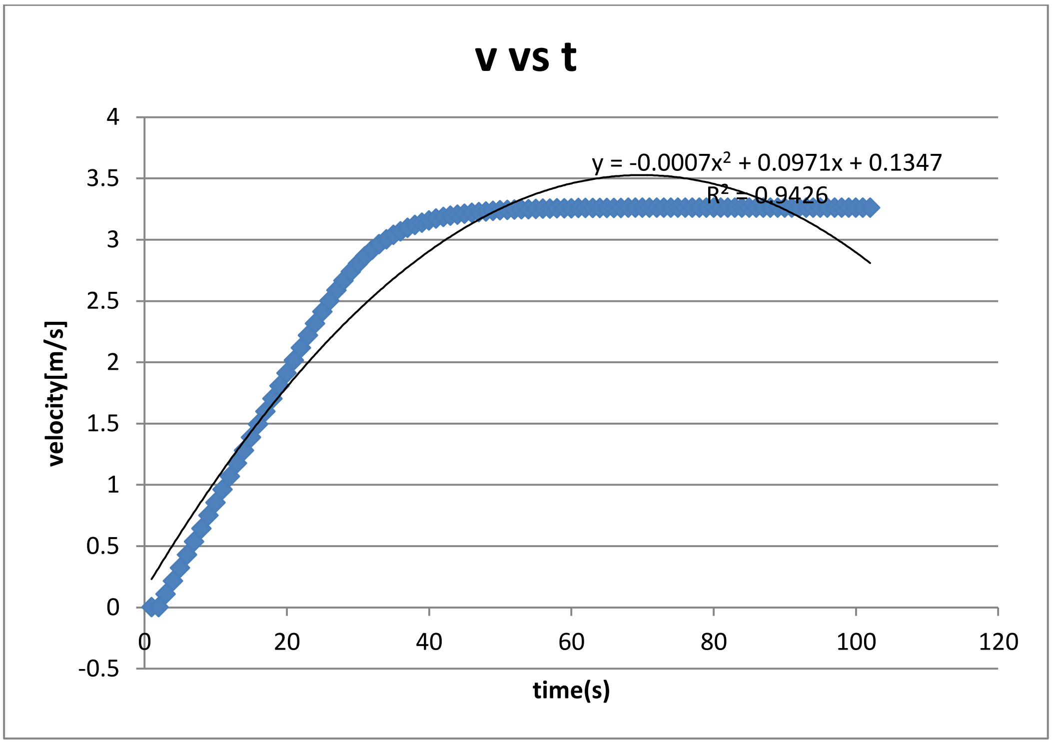
Area of solar panel = 0.21(0.297)

= 0.0623 m^2

So the power absorbed by the solar panel = 800(0.0623)

= 49.84 W

<u>Case 1: At maximum velocity</u>



$$v := -0.0007 \cdot t^2 + 0.0971 \cdot t + 0.1347$$

$$\int_0^s ds = \int_0^t \left(-0.0007 \cdot t^2 + 0.0971 \cdot t + 0.1347\right) dt$$

➔ $s = -0.0002333333333\, t^3 + 0.04855000000\, t^2 + 0.1347000000\, t$

To find maximum velocity,

$$\frac{dv}{dt} = 0$$

→ $-0.0014\,t + 0.0971 = 0$

t= 69.35s, which is the time when the SSV reach maximum velocity

Substituting t=69.35s for the velocity equation

Then, Vmax= 3.5 m/s

Electric power supplied to motor by solar panel:

Terminal voltage = E +RI

Back emf, E = 60*Ce*V_{max}*Gear ratio/(2*Pi*r) where V_{max}= 3.5 m/s^2

= 8.2 V

I = Isc-Is*(exp((E+I*R)/(m*N*Ur))-1) ;

Where R=3.32; Isc= 0,88 A; Is = 10e-8 A/m^2; m = 1.1; N =16; Thermal Voltage Ur = 0,0257 V

Using maple ; I = 0.395 A

Terminal voltage: U = E + I*R = 8.2+0.395*3.32 = 9.51V

Power delivered to motor by solar panel = U *I

= 3.75W

Power lost as heat due to armature resistance:

Power lost due to armature resistance = I^2*R

= 0.395^2*3.32

= 0.518 W

Efficiency loss of motor:

Efficiency of motor = 84%

Power lost due to efficiency= 0.16*3.75

= 0.6W

Power delivered to shaft = Motor power – Efficiency loss – Heat loss

= 3.75-0.6-0.518

= 2.632W

Power loss due to Air resistance:

$F_w = \frac{1}{2}(Cw)(A)(\rho)(v^2)$

Where,

C_w= coefficient of wind.

A = area of the vehicle in contact with air.

ρ = density of the air.

v = velocity of the wind(max)

F_w = 0.5(0.5)(1.293)(0.02)$(3.5)^2$

= 0.0794 N

Power loss due to air friction = F_w(ds/dt)

= 0.0794*($-0.0007 \cdot t^2 + 0.0971 \cdot t + 0.1347$) [t=69.35]
= 0.0794*3.5

= 0.278 W

% Loss due to air friction = $\frac{\text{Power loss due to air friction}}{Motor\ Power\ delivered\ to\ shaft} \times 100$

= $\frac{0.278}{2.632} \times 100$ = 10.56% of motor power delivered is lost due to air resistance at maximum speed.

Rolling resistance:

$F_r = \mu(m)(g)$

= 0.012 (1.4)(9.8) = 0.164 N

Where,

μ = coefficient of friction.

m = mass of the SSV.

g = gravitational force.

Power loss due to rolling friction = F_r(ds/dt)

$= 0.164*(-0.0007 \cdot t^2 + 0.0971 \cdot t + 0.1347)$ [t=69.35]

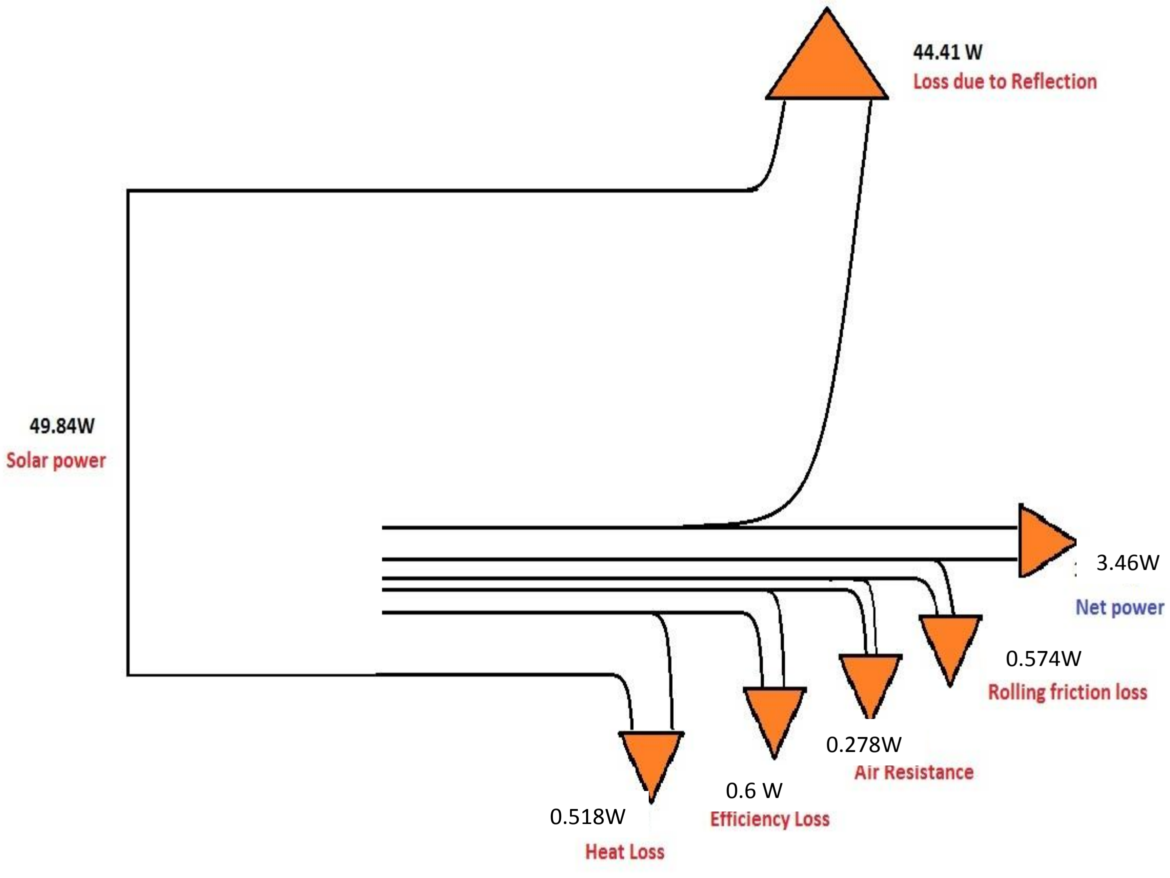
=0.164* 3.5

=**0.574 W**

% Loss due to rolling resistance = $\frac{\text{Power loss due to rolling friction}}{\textit{Motor power delivered to shaft}} \times 100$

$= \frac{0.574}{2.632} \times 100$

=21.81% of motor power is lost due to rolling friction between wheels and track at maximum speed.



Case 2: At half velocity

Half velocity= Vma/2=3.75/2= 1.75 m/s

$$v := -0.0007 \cdot t^2 + 0.0971 \cdot t + 0.1347$$

For v=1.75 m/s → t=19.32 s(which is the time to reach half velocity)

Electric power supplied to motor by solar panel:

Terminal voltage = E + IR^2

Back emf, E = 60*Ce*V_{half}*Gear ratio/(2*Pi*r) whereV_{half} = 3.5/2 m/s=1.75 m/s

E=4.1 V

I = Isc-Is*(exp((E+I*R)/(m*N*Ur))-1) ;

Where R=3.32; Isc = 0,88A; Is = 10e-8A/m^2; m = 1.1; N = 16; Thermal Voltage Ur = 0.0257 V;

Using maple; I = 0.871 A

Terminal voltage: U = E + I*R

= 4.1+0.871*3.32

= 7 V

Power delivered to motor by solar panel = 7*0.871

= 6.079W

Power lost as heat due to armature resistance:

Power loss by motor resistor= I^2*R

= 0.871^2 *3.32

= 2.51W

Motor Efficiency loss :

Efficiency of motor = 84%

Power Loss = 0.16 *6.079

=0.97W

Power delivered to shaft = Motor power – Efficiency loss – Heat loss

= 6.079-0.97-2.51

= 2.599W

Power loss due to Air resistance:

$F_w = \frac{1}{2}(Cw)(A)(\rho)(v^2)$

= 0.5(0.5)(1.293)(0.02)$(1.75)^2$

= 0.024 N

Power loss due to air friction = $F_w(ds/dt)$

=0.024*($-0.0007 \cdot t^2 + 0.0971 \cdot t + 0.1347$) [t=19.32s]

= 0.024 * 1.75

= 0.042 W

Efficiency = $\frac{\text{Power loss due to air friction}}{Motor\ power\ delivered\ to\ shaft} \times 100$

= $\frac{0.042}{2.599} \times 100$

= 1.6% of motor power delivered to shaft is lost due to air resistance at half speed.

Rolling resistance:

$F_r = \mu(m)(g)$

= 0.012 (1.4)(9.8) = 0.164 N

Where,

μ = coefficient of friction.

m = mass of the SSV.

g = gravitational force.

Power loss due to rolling friction = $F_r(ds/dt)$

= 0.164($-0.0007 \cdot t^2 + 0.0971 \cdot t + 0.1347$) [t=19.32]

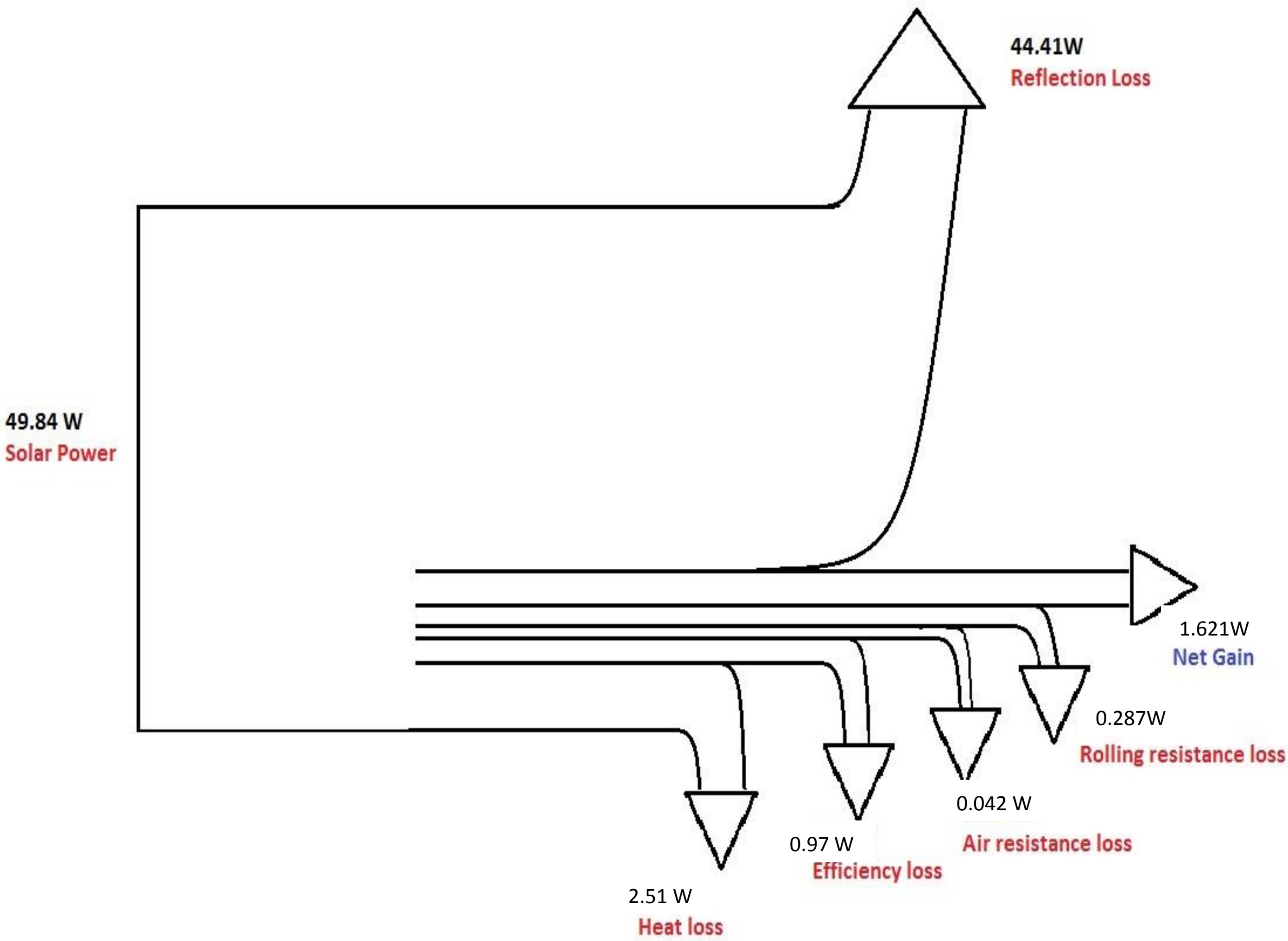
=0.164*1.75

= 0.287W

$$\% \text{ lost} = \frac{\text{Power loss due to rolling friction}}{\text{Solar power delivered to shaft}} \times 100$$

$$= \frac{0.287}{2.599} \times 100$$

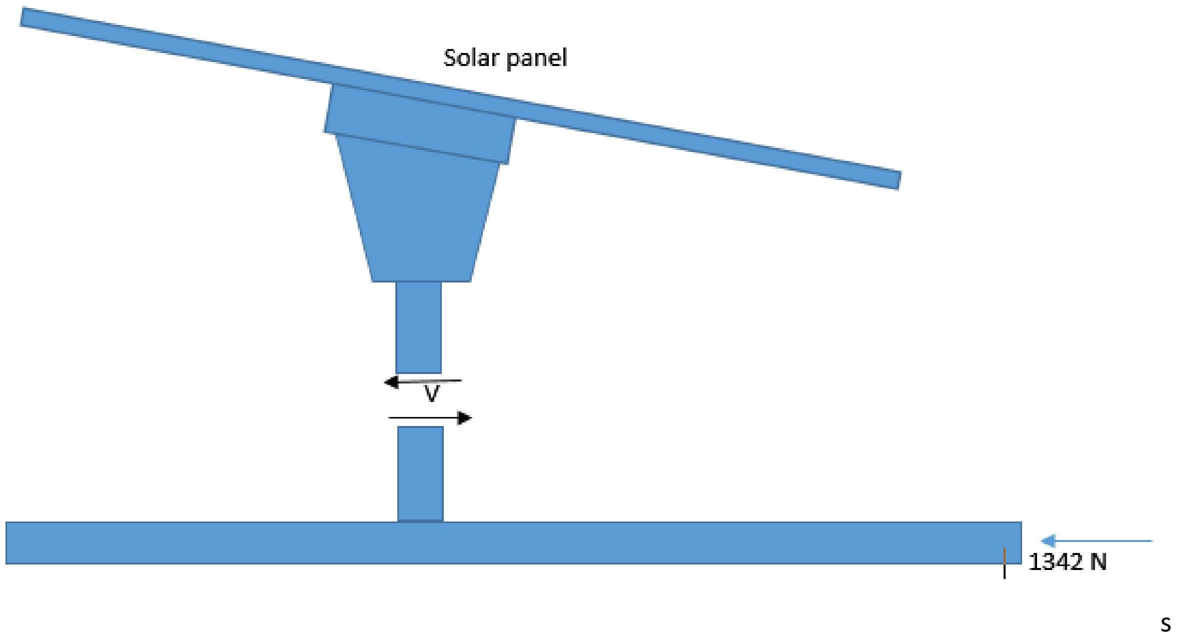
= 11.04% motor power of lost due to rolling friction between wheels and track at half speed.



Strength calculations to analyse whether your SSV will survive the load during impact.

From the collision test(test run) , we found that the maximum force during the collision to be 1342N.

Stresses on Solar panel Support



Sheer force at the cross section is 1342 N

The support is a plastic material with a diameter of 7 mm

Diameter = 7 mm

= 0.007 m

Area of cross section = $3.14 * 0.007^2/4\ m^2$

= $3.8 * 10^{-5}\ m^2$

Sheer stress = $1342 / (3.8 * 10^{-5})$

= 35.3 M Pa

The maximum sheer stress of the plastic we used is approximately 150 M Pa

The maximum force before failure at the support of solar panel, F_{max}= $Stress_{sheer,max.}$* Area

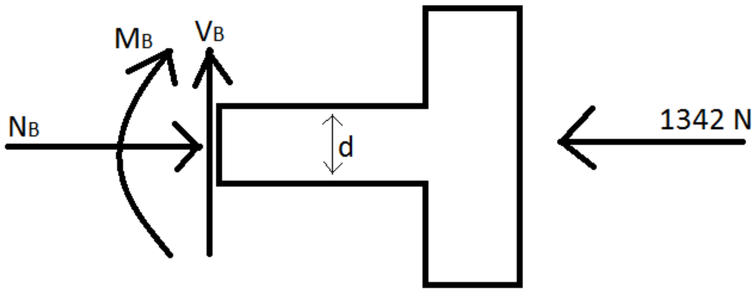
= $150*10^6*3.8*10^{-5}$

= 5.7 kN

Stresses on the hitting support

The figure shows the SSV to which the force of 1342N is acted upon. The hitter(which is of steel in our SSV) experience normal stress during the collision process.

Free Body Diagram :



Diameter of hitting component d = 0.015 m

N_B = +1342 N

V_B = 0 N

M_B = 0 N.m

Then, $\sigma = \frac{1342\ N}{\pi\ x\ (0.015\ m)^2}$ = 1.89 MPa

From the property of steel Yield stress = 250 MPa

Therefore, σ << 250 MPa

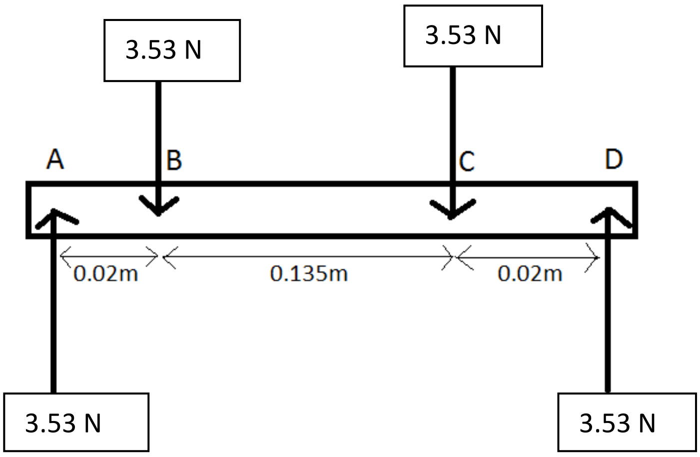
So, we can see that the normal stress is significantly below the Yield stress.Therefore, we the hitter part can survive the collision during the race.

The max force ,Fmax= 250 Mpa * $\pi\ x\ (0.015\ m)^2$

=176.71 KN

Stresses on the shaft:

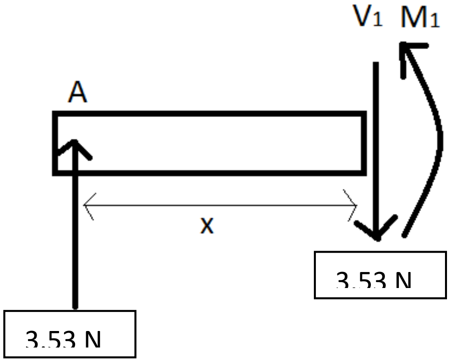
Forces on the shaft:



There are no normal forces acting on the shaft. This means that average normal stresses on the shaft are zero.

We neglected the weight of the shaft and forces acting due to gear.

Therefore the shear stress between A and B:



Shear force V_1 = 3.53

M_1(CCW) = 3.53*x

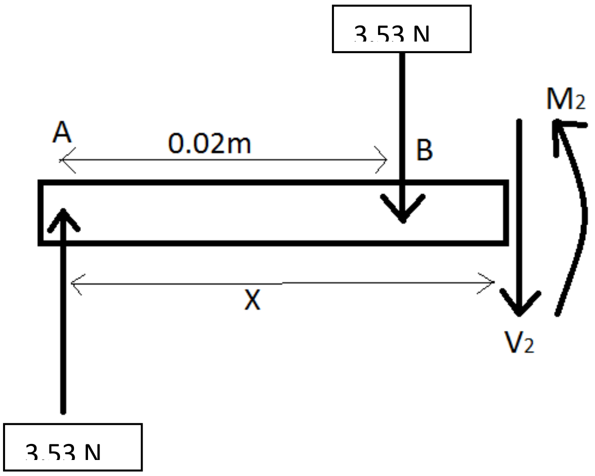
Shear stress $\sigma_1 = \frac{3.53}{\frac{\pi\,x\,d^2}{4}}$

$$= \frac{(3.53)\,x\,4}{\pi\,x\,(4.1\,x\,10^{-3})^2}$$

$$= \frac{14.12}{\pi\,x\,16.81\,x\,10^{-6}}$$

$= 0.27$ MPa

Stresses between B and C:

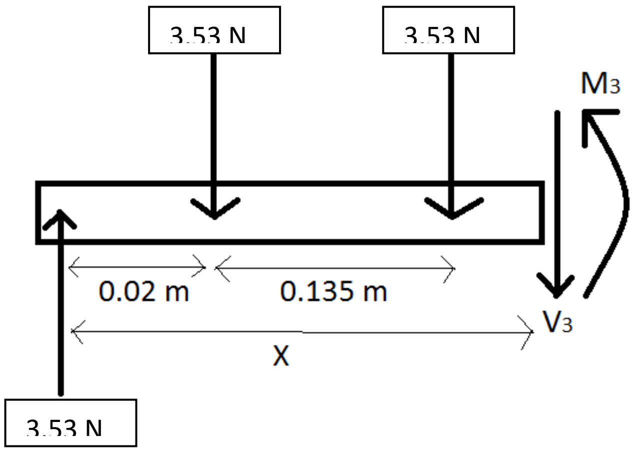


$V_2 = 0$

$\sum M(CCW) = 0$ ⇔ $M_2 + 3.53*(x - 0.02) - 3.53*x = 0$

⇔ $M_2 = 0.0706$ N.m

Stress between C and D:

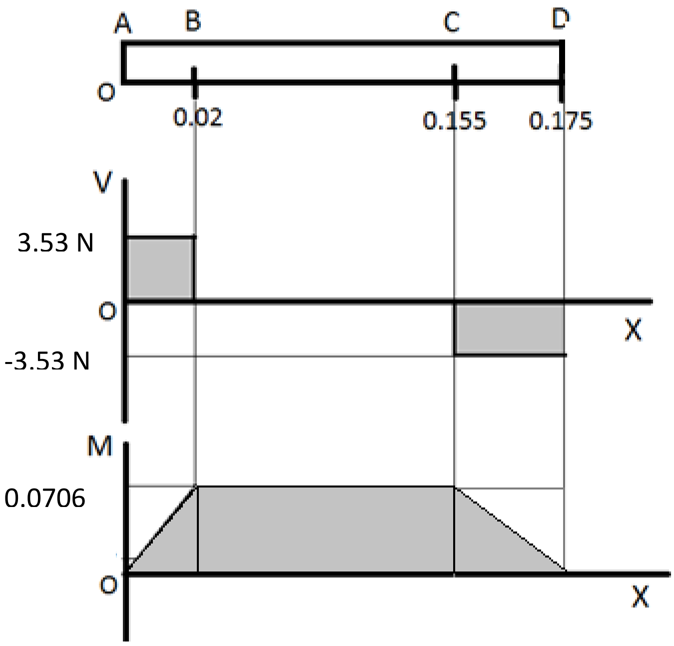


$V_3 = - 3.53$ N

$\sum M(CCW) = 0$ ⇔ $M_3 + 0.35.(X - 0.02) - 0.35X + 0.35.(X - 0.155) = 0$

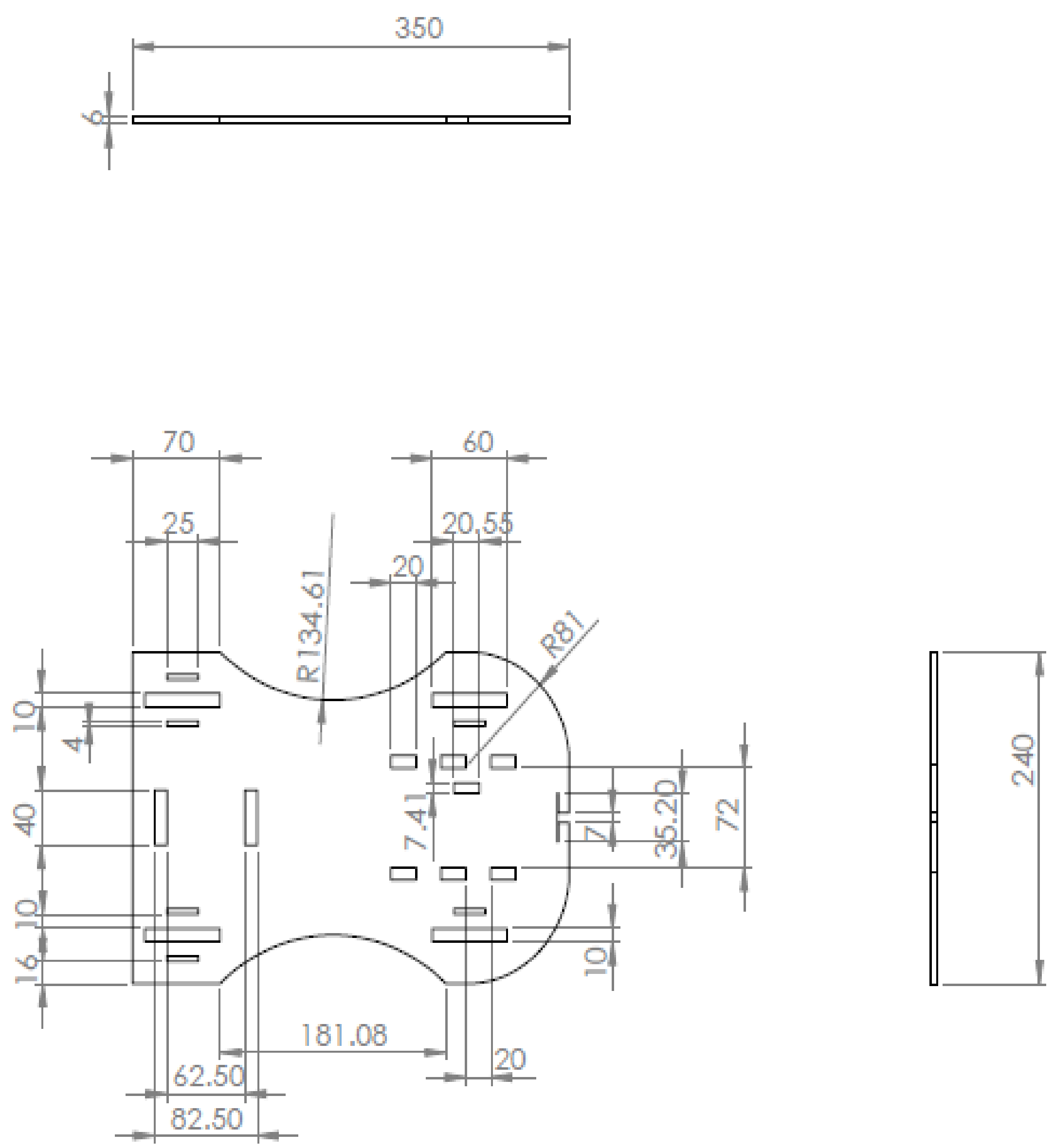
⇔ $M_3 = 0.61775 - 3.53X$

Total picture:



Analysing the forces involved in the support, hitter and the shaft we found maximum stress being applied at the solar support i.e. 35.3MPa and the maximum force is 5.7 kN approximately. We made all these calculations by simplifying the design of SSV.

2D technical drawing of the frame of your SSV.



Analysis of collision process

Object A and B (their mass are both 2 kg) are connected by a spring (the weight of the spring can be neglected), they are sliding on an icy surface (no friction loss) with the same speed: v=6m/s, the spring is at its original length.

Another object C (mass 4kg) is standing still in front and in the moving direction of A and B, as shown in Figure 2.

The collision between B and C is perfectly-inelastic. The spring is sufficiently long (so that A and B will not physically touch each other during the whole process). Except for the spring, the objects are all perfectly rigid.

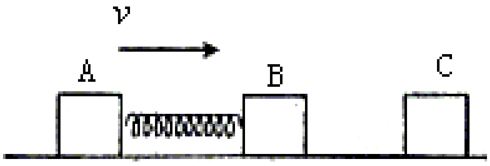


Figure 2: initial situation of the objects before collision

a) *What is the movement speed of object B and C after collision?*

Due to conservation of momentum we can say that:

$$m_B v_B + m_C v_C = (m_B + m_C)v'$$

We know that $v_A = v_B = 6\frac{m}{s}$ and v_C is zero in the beginning,

$$(2kg).(6\frac{m}{s}) = (2kg + 4kg).v'$$

$$v' = 2\frac{m}{s}$$

b) *What is the speed of object A, when the potential energy in the spring reaches its maximum?*

$$m_A v_A + m_{BC} v_{BC} = (m_A + m_B + m_C).v''$$

$$(2kg).(6\frac{m}{s}) + (2kg + 4kg).(2\frac{m}{s}) = (2kg + 2kg + 4kg).v''$$

$$v'' = 3\frac{m}{s}$$

c) *How much is the maximum spring potential energy?*

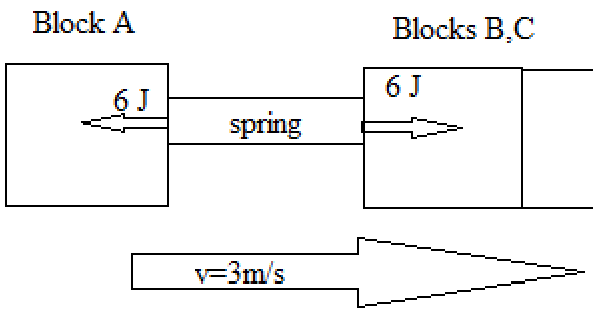
$$\frac{m_A {v_A}^2}{2} + \frac{m_{BC} {v_{BC}}^2}{2} = \frac{m_A {v_A}^2}{2} + \frac{m_{BC} {v_{BC}}^2}{2} + E$$

$$\frac{(2kg).(6\frac{m}{s})^2}{2} + \frac{(6kg).(2\frac{m}{s})^2}{2} = \frac{(2kg).(3\frac{m}{s})^2}{2} + \frac{(6kg).(3\frac{m}{s})^2}{2} + E$$

$$E = 12\,J$$

d) Is it possible for object A to reverse the direction of its speed at any point during its oscillation?

Maximum Spring Energy =12 J, at that instance, all blocks have same velocity(3m/s). So difference in relative kinetic energy is zero. In the next instance, when the spring start to release its energy, half of the spring potential energy i.e. 6Joules will be distributed to each side.



Block A will have kinetic energy of 9 J (from calculation below)

Ke(A) =(mass*v^2)/2 Joules = 2*9/2 = 9 Joules.

Thus the energy transfer from the sprig is less than the kinetic energy of the block A,hence the velocity of block A will not reverse.